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GUIDE TO POWER BOAT DESIGN

by Joseph G. Koelbel, Jr.

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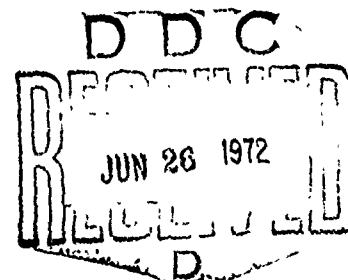
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13. ABSTRACT

*The report.*  
This work is intended primarily to outline the present state-of-the-art in small craft design. This is done by providing a brief partially annotated bibliography of current references most useful to the practicing designer. If he uses these references, he can be reasonably sure that he has the best information that was available in late 1970 or early 1971. A secondary aim of this work is to emphasize the areas in which very little design information is presently available.

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## I. INTRODUCTION

### A. PURPOSE

This work is intended primarily to outline the present state of-the art in small craft design. This is done by providing a brief partially annotated bibliography of current references most useful to the practicing designer. If he uses these references, he can be reasonably sure that he has the best information that was available in late 1970 or early 1971. The references considered most useful have been asterisked. Readers interested in investigating a particular subject further are referred to the companion work to this guide, "Bibliography on Power Boat Design", and to the bibliographies contained in many of the references cited in the present works. Abstracts of many of the works cited here will be found in the "Bibliography".

A secondary aim of this work is to emphasize the areas in which very little design information is presently available. Some of these areas are:

1. Hydrodynamics of unsymmetrical planing:
  - a. Transverse stability at planing speeds
  - b. Prediction of bank angle as a function of speed and turning radius
2. Maneuvering
  - a. Prediction of turning radius at any speed
  - b. Exact prediction of required rudder size for various degrees of maneuverability.
3. Design of high speed rudders and other appendages

4. Design of transom flaps
5. More accurate prediction of propulsive characteristics; for example, estimation of wake fraction and thrust deduction for various arrangements of appendages (including stern drives and pod drives) on planing boats, particularly at planing speeds, estimation of relative rotative efficiency, prediction of cavitation in non-uniform flow, etc.
6. Prediction of resistance and trim at hump speeds by direct calculation rather than by specific model tests.
7. Prediction of shallow water effects.
8. Accurate calculation of hull loadings, particularly bottom pressures as a function of hull shape and size, as well as speed and sea-state.
9. Prediction of vibration problems arising from any source, particularly propellers.
10. Rigorous structural analysis.

These are just some of the areas where more information is needed. Actually, research work is being done in all these areas and new reports are being issued frequently. It is hoped that this guide and the bibliography will be brought up to date periodically. It is stressed that suggestions, criticisms, additions, and corrections are welcomed. These

comments and copies of additional entries should be submitted to  
NAVSECNORDIV 6660.03, U. S. Naval Station, Norfolk, Virginia 23511.

#### B. SCOPE

Regarding the subject matter covered by this guide, the greatest emphasis is placed on the hydrodynamics of the hull and on performance prediction. Propulsion is given nearly as much emphasis but structural design is covered merely with a list of important references relating to most of the commonly used materials. The publications of the various associations are too numerous to list separately, but because they are valuable to the designer the addresses of the associations are listed in the structural section.

#### C. COMPUTER PROGRAMS

There are a number of computer programs available for use in power boat design. They perform the following calculations:

Hydrodynamics (Trim, Resistance, Power, etc.)

Bonjean's Curves

Curves of Form (Displacement, Center of Buoyancy, Metacentric Radius, Moment to Trim, etc.)

Cross Curves of Stability

Floodable Length

Damaged Stability

Propeller Selection from Standard Series

Ship Motions (limited applicability)

In addition to making the calculations, the output can be plotted by machine. Sources for this work include some of the colleges or universities, some of the towing tanks, and certain firms or individual naval architects who specialize in computer applications.

## II. BASIC REFERENCES

The basic references which will provide the designer with a good background in naval architecture, its application to small craft, and a general philosophy of small power boat design are the following:

- \*1. Principles of Naval Architecture, by a group of authorities, 1967, SNAME
- \*2. Basic Naval Architecture, by K. C. Barnaby, 1960, John de Graff, Inc., 34 Oak Avenue, Tuckahoe, N.Y. 10707
- \*3. Hydrodynamics in Ship Design, by H. E. Saunders, Three Volumes, 1957 and 1965, SNAME
- \*4. Naval Architecture of Small Craft, by D. Phillips-Birt, 1957, The Philosophical Library, 15 East 40th Street, New York, N.Y. 10016
- \*5. High Speed Small Craft, by P. DuCane, 1960, Temple Press Ltd., Bowling Green Lane, London E.C.I.
- \*6. Fishing Boats of the World, edited by J. O. Traung, Three Volumes, 1955, 1960, 1967, Fishing News (Books) Ltd., 110 Fleet Street, London, E.C.4., England
- 7. Stability and Trim of Fishing Vessels, by J. A. Hind, 1967, Fishing News (Books) Ltd. 110 Fleet Street, London, E.C.4., England

References 6 and 7 should not be overlooked by the planing boat designer because of their titles. There is a wealth of small craft naval architecture in them, particularly the former. Reference 3 is essential because of its broad and thorough treatment of hydrodynamics and because of the many references it cites. Reference 5 is considered the definitive work on all aspects of planing boat design.

Works concerned exclusively with planing boat hull performance are:



- \*8. How to Design Planing Hulls, by J. Stoltz, J. G. Koelbel, Jr., and J. Beinert, 1963, Vol. 49, Ideal Series, Motor Boating, 959 Eighth Avenue, New York, N.Y. 10019
- \*9. "Hydrodynamic Design of Planing Hulls", by D. Savitsky, 1964, Marine Technology Vol. 1, No. 1, SNAME
- \*10. "Stepless and Stepped Planing Hulls - Graphs for Performance Prediction and Design", by E. P. Clement and J. D. Pope, 1961, Report 1490, DTMB

Reference 8 is a good one to start with because of its approach to the subject, while References 9 and 10 are essential because of their treatment of the subject. Four different viewpoints on the understanding and calculation of planing phenomena are presented in these works.

Another approach (applicable only to stepped boats) which is worth consideration is given in:

- 11. "A Lifting Surface Approach to Planing Boat Design", by E. P. Clement, 1964 DTMB Report 1902

Further understanding of the limitations, the history, and the possibilities of planing boat design may be found in the following:

- \*12. "Analyzing the Stepless Planing Boat", by E. P. Clement, 1956, DTMB Report 1093
- \*13. "Development and Model Tests of an Efficient Planing Hull Design", by E. P. Clement, 1959, DTMB Report 1314
- 14. "Performance Limits of the Stepless Planing Boat and the Potentialities of the Stepped Boat", by E. P. Clement, 1966, Symposium on Small Craft Hydrodynamics, South East Section, SNAME

15. "Graphs for Predicting the Ideal High-Speed Resistance of Planing Catamarans", by E. P. Clement, 1961, DTMB Report 1573
- \*\*16. "Evaluation of the Quality of Planing Boat Designs", by J. C. Angeli, Feb. 18, 1971, South East Section, SNAME
17. "Motor Torpedo Boat Comparison", by W. C. Hugli, Jr., 1940 ETT Tech. Memo No. 54

For a broad view of the economy of transportation and of the limits of speed for various vehicles (and the place of boats in the overall spectrum) see the following classical papers:

18. "What Price Speed? Specific Power Required for Propulsion of Vehicles", G. Gabrielli and Th. von Karman, Oct. 1950 issue of Mechanical Engineering.
19. "What Price Speed? Long Range Trends in Overseas Transportation", by K. S. M. Davidson, Oct. 14, 1954, Chesapeake Section SNAME, Reprinted in SNAME Bulletin, Feb. 1955

### III. PERFORMANCE DATA ON VARIOUS BOAT TYPES

#### A. GENERAL AND V-BOTTOM

Much additional information on hull characteristics of planing boats of various types may be found in:

- \*20. "Hydrodynamic Characteristics of Basic Planing Hull Types", by P. Van Meter and H. Dornak, 1965, Great Lakes Section S.S.C.D.
- \*21. "The Seaworthiness Problem in High Speed Small Craft", by S. C. McGown, Jan. 24, 1961, New York Metropolitan SECTION, SNAME
22. "Comparative Resistance Data for Four Planing Boat Designs", by E. P. Clement and P. M. Kimon, 1957, DTMB Report 1113

23. "Smooth Water Resistance of a number of Planing Boat Designs", by E. P. Clement and C. W. Tate, 1959, DTMB Report 1378

- \*24. "The Detail Design of Planing Hull Form", by J. G. Koelbel, Jr., 1966, Symposium on Small Craft Hydrodynamics, South East Section, SNAME

The following reference presents test data on the "Clement" hull form, the development of which is described in Reference 13, for a wide variety of proportions and loadings.

- \*25. "Resistance Tests of a Systematic Series of Planing Hull Forms", by E. P. Clement and D. I. Blount, 1963, Transactions, SNAME

#### B. ROUND BOTTOM BOATS

Information on the characteristics of round bottom boats may be found in the following:

- \*26. "Series 63, Round Bottom Boats", by P. M. Beys, 1963, DL Report 949
- \*27. "Resistance and Propulsion Characteristics of a Round Bottom Boat (Parent Form of TMB Series 63)", by D. L. Blount, DTMB Report 2000
- \*28. "Model Tests of a Series of Six Patrol Boats in Smooth and Rough Water", by Young Chey, 1963, DL Report 985
29. "Model Tests of a Round Bottom Patrol Boat in Smooth and Rough Water", by G. Fridsma, 1965, DL Report LR-1074
30. "Series 64 Resistance Experiments on High Speed Displacement Forms", by Hugh Yeh, July 1965, Marine Technology, SNAME

31. "Merit Comparisons of the Series 64 High Speed Displacement Hull Forms", by E. P. Clement, 1965, DTMB Report 2129
32. Elements of Yacht Design, by N. L. Skene, 1935, Dodd, Mead and Co. (Out of print)
33. "Design Data for High Speed Displacement-Type of Hulls and a Comparison with Hydrofoil Craft", by W. J. Marwood and A. Silverleaf, 1960, Third Symposium on Naval Hydrodynamics, ACR-65, Supt. of Documents, U. S. Government Printing Office, Washington 25, D. C.
- \*34. "A Critical Review of Several Reports on Round Bottom Boats", by E. P. Clement, 1963, Tech. Note No. 40, DTMB
35. "Resistance and Propulsion of Motor Boats", by D. de Groot, 1955, International Shipbuilding Progress, Vol. 2, No. 6
36. "Hydrodynamics of High Speed Ships", by P. R. Van Mater, Oct. 1961, DL Report 876

#### C. STEPPED HULLS

Data on stepped hulls may be found in References 14 and 23, previously cited, and in:

37. "Stepped Planing Boats, Some Full-Scale Test Results", by A. M. Lippisch and R. E. Colton, May 1970, T and R Report R-9, SNAME
38. "Model Tests of a Stepped Planing Boat with an Adjustable Stern Stabilizer", by E. P. Clement, 1967, DTMB Report 2414
39. "Effect of Length-Beam Ratio on the Performance of a Stepped Planing Boat with an Adjustable Stern Stabilizer", by E. P. Clement, 1967, DTMB Report 2552

40. "The Design of Cambered Planing Surfaces for Small Motorboats", by E. P. Clement, 1969, DTMB Report 3011

References 38 and 39 are concerned exclusively with a special design known as the "Dynaplane", equipped with a "Plum stabilizer" named after its originator, John Plum, while Reference 37 details the development of a practical stepped, vee-bottom hull of quite conventional form.

D. CAMBERED PLANING SURFACES AND TRIM FLAPS

Data on cambered planing surfaces may be found in Reference 40, above, and in:

41. "The Planing Characteristics of a 15-Degree Deadrise Surface with Circular Camber", by E. P. Clement 1966, DTMB Report 2298
42. "Cambered Planing Surfaces for Stepped Hulls - Some Theoretical and Experimental Results", by W. L. Moore, 1967, DTMB Report 2387
43. "Graphs for Designing Cambered Planing Surfaces Having the Johnson Three-Term Camber Section, Rectangular Planform, and Zero Deadrise", by E. P. Clement, 1969, NSRDC Report NO. 3147

Reference 40 is a good introduction to the subject of cambered planing surfaces and gives design information on a specific set of design parameters (e.g. deadrise = 7.5 degrees, aspect ratio = 1.5). Additional information on deadrise surfaces with circular arc camber for a wide variation of parameters is given in Reference 41. References 42 and 43 apply only to flat bottom surfaces.

None of the above information is applicable to wedges or trim flaps, but there are two unpublished reports which give quantitative information:

44. "Evaluation of the Effect of Flaps on the Trim and Drag of Planing Hulls, by J. C. Angeli, 1970
45. "Hydrodynamic Characteristics of Flap-Equipped Planing Surfaces", Anonymous, 1967, DL

It is hoped that both of these references will be made available in the future. The former is more readily useable than the latter.

E. INVERTED V

Data on inverted vee surfaces may be found in References 21, 23 and:

46. "The Planing Characteristics of an Inverted V Prismatic Surface with Minus 10 Degrees Deadrise", by P. M. Kimon, 1957, DTMB Report 1076
47. "Hydrodynamic Impact Loads of a Minus 20 Degree Deadrise Inverted V Model and Comparisons with Loads of a Flat-Bottom Model", by P. M. Edge, Jr., 1958, NACA TN 4339

F. SPECIAL TOPICS

a. Spray Strips

Information on the effects of spray strips may be found in Reference 22 and in:

- \*48. "Effect of Spray Strips on Various Power Boat Designs", by R. Ashton, 1949, EST Tech. Memo No. 99
- \*49. "Effects of Longitudinal Bottom Spray Strips on Planing Boat Resistance", by E. P. Clement, 1964, DTMB Report 1818
50. "Reduction of Planing Boat Resistance by Deflection of the Whisker Spray", by E. P. Clement, 1964, DTMB Report, 1929

Additional theoretical and experimental information on the formation of spray by a planing surface may be found in:

51. "On the Main Spray Generated by Planing Surfaces", by D. Savitsky and J. Breslin, Jan. 1958, SMF Fund Paper No. FF-18, Institute of the Aeronautical Sciences, N.Y.
52. "Turbulence Stimulation in the Boundary Layer of Planing Surfaces, Part II, Preliminary Experimental Investigation", DL Report 444

b. Shallow Water

There is very little quantitative information on the shallow water performance of planing boats. One of the best reports is:

53. "Shallow Water Performance of a Planing Boat", by A. Toro, 1969, Symposium on Small Craft Technology, South East Section, SNAME

The following report is of less use to the planing boat designer but it gives some additional background from the seaplane field.

54. "Effect of Shallow Water on the Hydrodynamic Characteristics of a Flat-Bottom Planing Surface", by K. W. Christopher, 1956, NACA TN 3642

c. Maneuvering and Rudders

The best report on steering of planing boats (e.g. estimating turning radius) is:

- \*55. "On the Maneuverability of the High Speed Boat", by Kazuo Sugai, 1964, Bureau of Ships Translation No. 868, AD 463 211

Reference 55 includes much useful information on the size and proportions of rudders, placement of rudders relative to screws, size of skegs, etc. Additional information on the sizing and design of rudders may be found in References 1, 2, 3, 4, 5 and:

56. "Rudder Design for Planing Craft", by D. Hall, The Planimeter, Oct. and Nov. 1962, SSCD
57. "Some Notes on the Steering of High Speed Planing Hulls", by T. Grenfell, 27 Sept. 1952, Pacific Northwest Section SNAME, also in SNAME Bulletin, Jan. 1953
58. "Interaction Between Single Screw Propellers and Twin Rudders Placed Symmetrically in the Screw Race", by K. Kafali, 1959 ASNE, also in ISP, July 1959
59. "Effects of Variations in the Thickness/Chord Ratio of Rudders in a Slip Stream", Jan. 1952 DTMB Report No. C-487
60. "Free Stream Characteristics of a Family of Low Aspect Ratio All-Moveable Control Surfaces for Application to Ship Design", by L. Folger, et. al, Dec. 1958, DTMB Report 933
61. "Report on Rudder Torque Obtained from Tests of EX-PT 8 Motor Torpedo Boat", by J. H. Curry, Apr. 1950, DTMB Report C-301
62. "Rudder Dimensioning", Note No. 166, by J. C. Angeli, to be published

d. Porpoising

There are two criteria for porpoising limits. One, based on prismatic models is given in Reference 9. The other in Reference 25, gives the stability limits of the Series 62 models.



#### IV. METHODS OF CALCULATION

##### A. GENERAL

Basically, there are three methods of performance calculation:

a) The use of simple charts or equations which relate the weight, the power, the speed, and perhaps the length or beam of the boat. This method is quick and easy but has a number of drawbacks which will be explained in Section IV. B.

b) Direct calculation from planing equations which were derived from tests of prismatic (constant cross section) models. This method has the advantage of taking into account all the important factors which influence planing performance. It has the disadvantage that for boats with large variations in cross section with length and for conditions where much of the curved portion of the bow is in the water, the predictions are not exact. For most design work these disadvantages have not proven to be serious as long as care is taken in judging the effects of the variations from a constant section.

c) Prediction from tests of boat shaped (rather than prismatic) models, either a systematic series or an individual hull. In the latter case it may be a model of the new design or of a similar design. It is only in the case of a model that is geometrically similar to the full scale boat that the prediction is a straight forward matter, and even then there are some questions about how to scale some components of resistance. When the model is different from the boat, care must be exercised to assure good results. As far as possible, guidelines will be given to assist the designer in exercising the required "care".

## B. CHARTS AND EQUATIONS FOR PRELIMINARY DESIGN

There are a number of simplified methods in common use for the prediction of power boat performance. They consider only a few of the factors which affect a boat's performance and consequently cannot be used to good advantage except with a family of designs in which the missing factors are similar in all boats. For general performance predictions they are inadequate. This inadequacy has been illustrated for a number of these methods in:

63. "A Comparison of Powering Methods", by J.G. Koelbel, Jr.,  
Dec. 1961, Planimeter, SSCD.

The methods compared in Reference 63 are all given in, or can be reduced to, the form of a curve of weight-horsepower ratio plotted against either the speed or the speed-length ratio. With these plots, not only is the basic comparison inadequate for most work but the method of plotting it is not the best. However, there are occasions in preliminary design work and in work on existing boats when only limited information is available. For these cases it is desirable to have an easy method of estimating speed or power, but for best accuracy the information must be handled in a dimensionally correct manner. This matter will be taken up after a brief discussion of the equations in common use for making speed-power estimates.

Bob Hobbs, in an unpublished report, lists 8 of these equations. Most of them can be found in References 2,4 and:

### 64. Naval Architecture of Planing Hulls

by L. Lord, 1954, Cornell Maritime Press,  
Cambridge, Md.

These equations can be put in the form  $V = C(P^m/\Delta^n)$ . The value of  $m$  varies from .338 to .572 and of  $n$  from .222 to 1.00. A brief study of the resistance curves presented in the references shows that they all have irregularities in them which would cause the exponents  $m$  and  $n$  to vary with speed, and from boat to boat. In fact, the speed-power curve of any given hull varies with loading.

The only hope for an equation of this kind then, lies in the possibility that for a number of boats considered normal for their type, the data will lie on a narrow enough band to permit a curve to be faired through it. The desirability of making quick preliminary powering estimates, the lack of good design data for many boat types, and the hope of finding some sort of hull efficiency index for judging the quality of a design, have prompted some recent investigations into this matter. Clement, in an unpublished report, compares the performance of 7 boats. The data for these boats is given in Table I. This information has been plotted in several ways, shown here as Figure 1 through 5. The figures show the difference in results produced by the different methods of plotting. In Figures 1 and 2 the data collapse well and a curve is faired through the points. Because of the simplicity of the functions used, Figure 2 is the more useful of the two, and the equation for its curve is shown in the figure. When put into the "standard" form it is:

$$V = 2.74 \frac{BHP^{0.551}}{\Delta^{0.476}}$$

Most of the data points lie within 10 percent of the curve. If more data points had been used, particularly at the ends, a different equation would have resulted. The fallacies in the assumptions of this approach are illustrated by plotting on Figures 1 and 2 the speed-power curves for boat 3, Table I, and for the parent form of Series 62 (from References 22 and 13 respectively). These 9 boats are all much the same type. To illustrate how far off the equation would be for another type, the curve for a 67-foot by 10-foot round bottom patrol boat (Reference 29) has also been added. In using the model data BHP/EHP was assumed equal to 2.0. In the opinion of the writer the equations are of little value but graphs such as Figure 2, when loaded with accurate data can be useful for preliminary design. Actually, the data collapse just as well in Figure 5, and the coefficients used there ( $BHP/\Delta V$  and  $V/\Delta^{1/6}$ ) are probably much more suitable for the collection and presentation of this kind of data.

TABLE I  
Planing Boat Data

Ident No.	Boat	W, lb.	Length, ft.	BHP	Max. V, knots	$F_V$	$\frac{R \cdot BHP}{W \cdot EHP} \times 10^4$	$\frac{R \cdot BHP}{W \cdot EHP}$	$\Delta$ , tons	$\frac{BHP}{\Delta}$	$\Delta^{1/6}$	$\frac{BHP}{\Delta^{7/6}}$	$\frac{V}{\Delta^{1/6}}$	$\frac{DHP}{\Delta^{1/6}}$
3	Elco Pt 622	111,000	76.4	4,440	42.3	3.6	0.308	11.7	49.6	89.5	1.916	46.7	22.1	2.12
3	Elco Pt 622	121,000	76.4	4,545	40.8	3.5	0.299	10.3	54.0	84.2	1.944	43.3	21.0	2.06
8	Brave	190,500		9,000	50.3	3.9	0.307	12.0	85.0	105.9	2.097	50.5	24.0	2.11
9	Mercury	219,500		10,500	52.	4.0	0.300	12.0	98.0	107.1	2.147	49.9	24.2	2.06
11	Jackie S.	13,450		900	50.	6.1	0.437	26.6	6.0	150.0	1.348	111.2	37.1	3.00
12	45' Rescue	32,000		900	33.	3.5	0.278	9.7	14.3	62.9	1.558	40.4	21.2	1.91
14	65' Picket	66,000		1,200	25.	2.4	0.237	5.6	29.5	40.7	1.758	23.1	14.2	1.52
17	Gee	18,000	40.	1,000	45.5	5.3	0.398	21.1	8.0	125.0	1.414	88.5	32.2	2.75

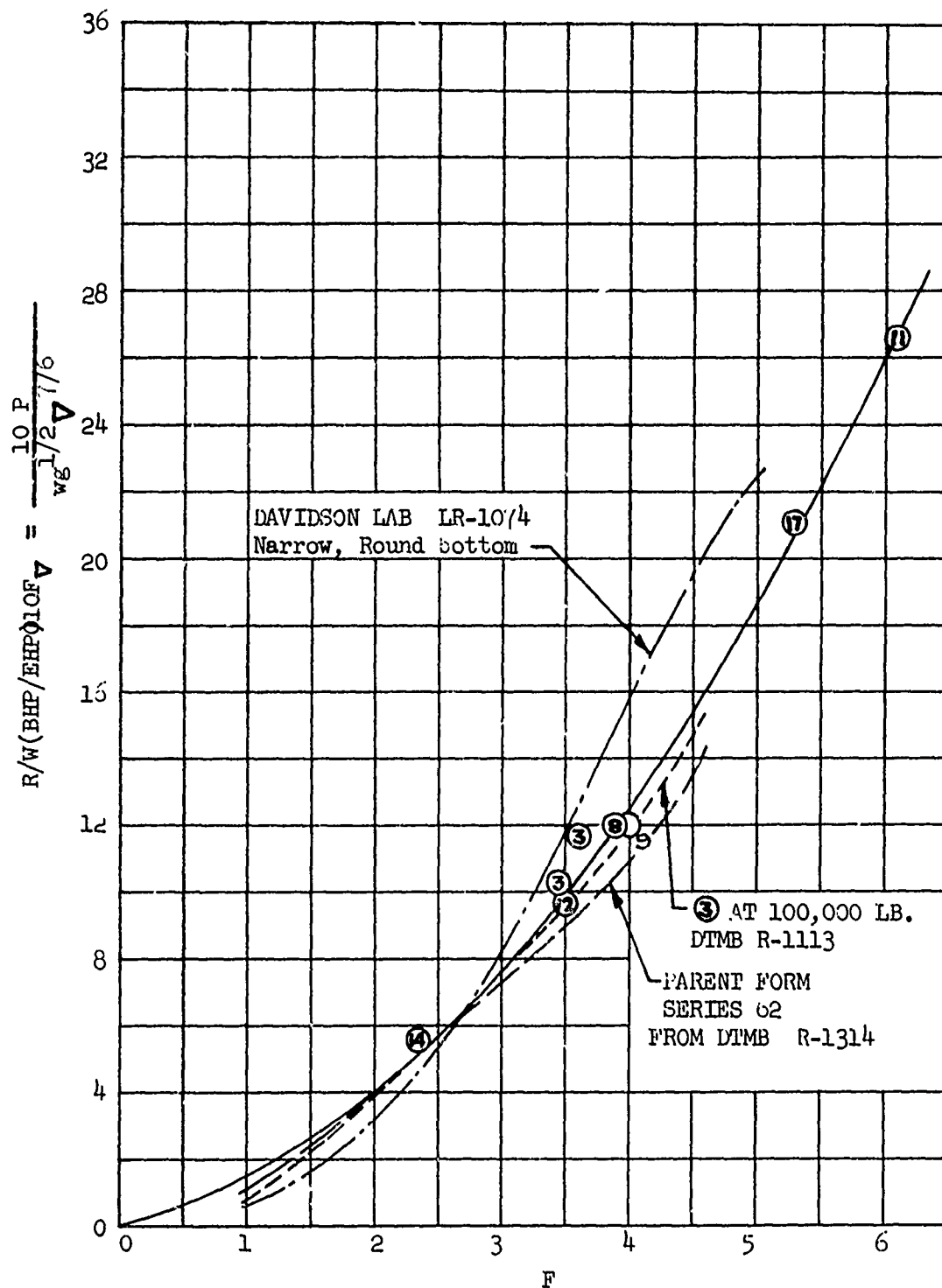


Figure 1.  $R/(W(BHP/EHP)LOF_{\nabla})$  vs.  $F_{\nabla}$  for several planing hulls

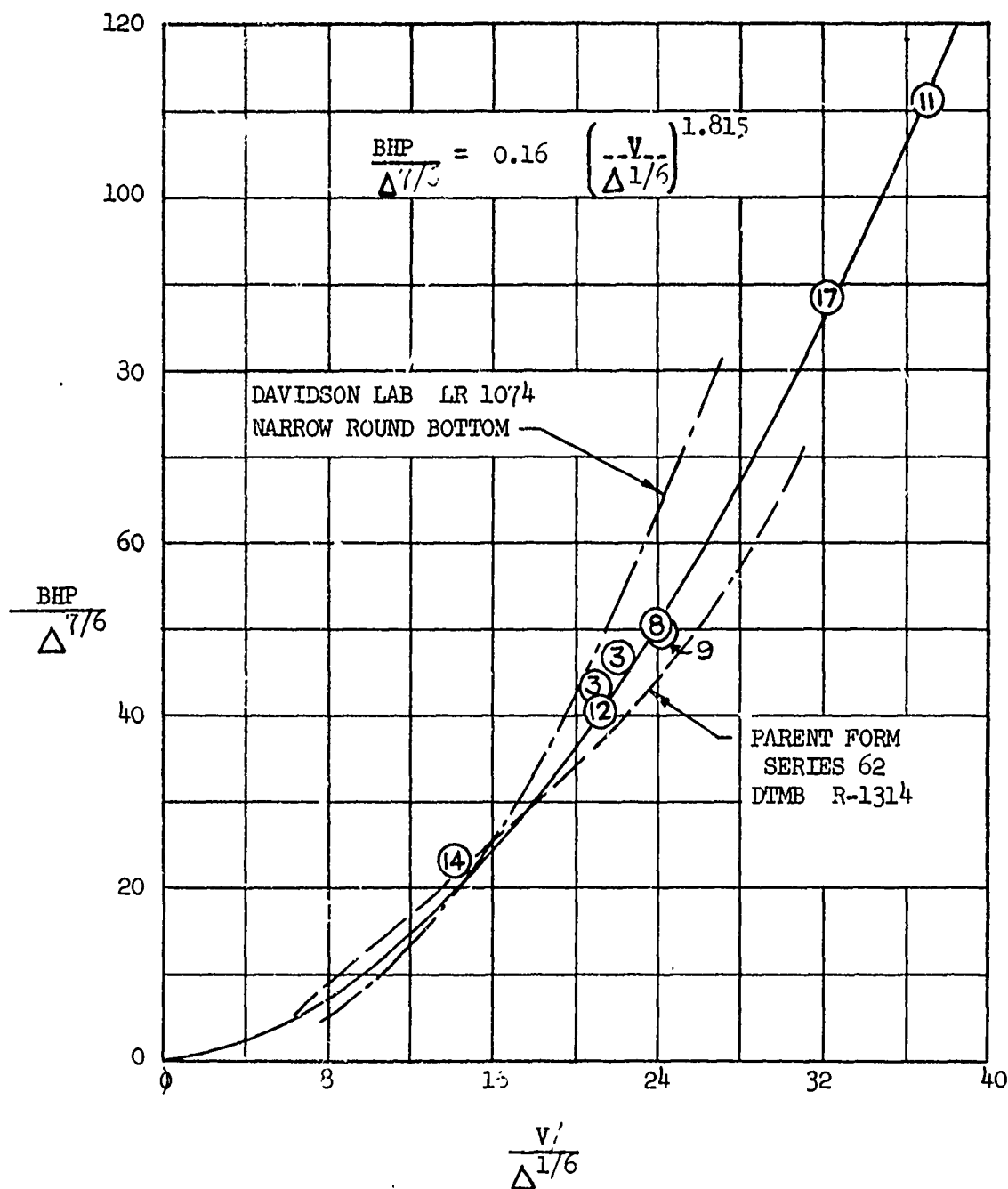


Figure 2.  $\frac{BHP}{\Delta^{7/6}}$  versus  $\frac{v}{\Delta^{1/6}}$  for several planing hulls.

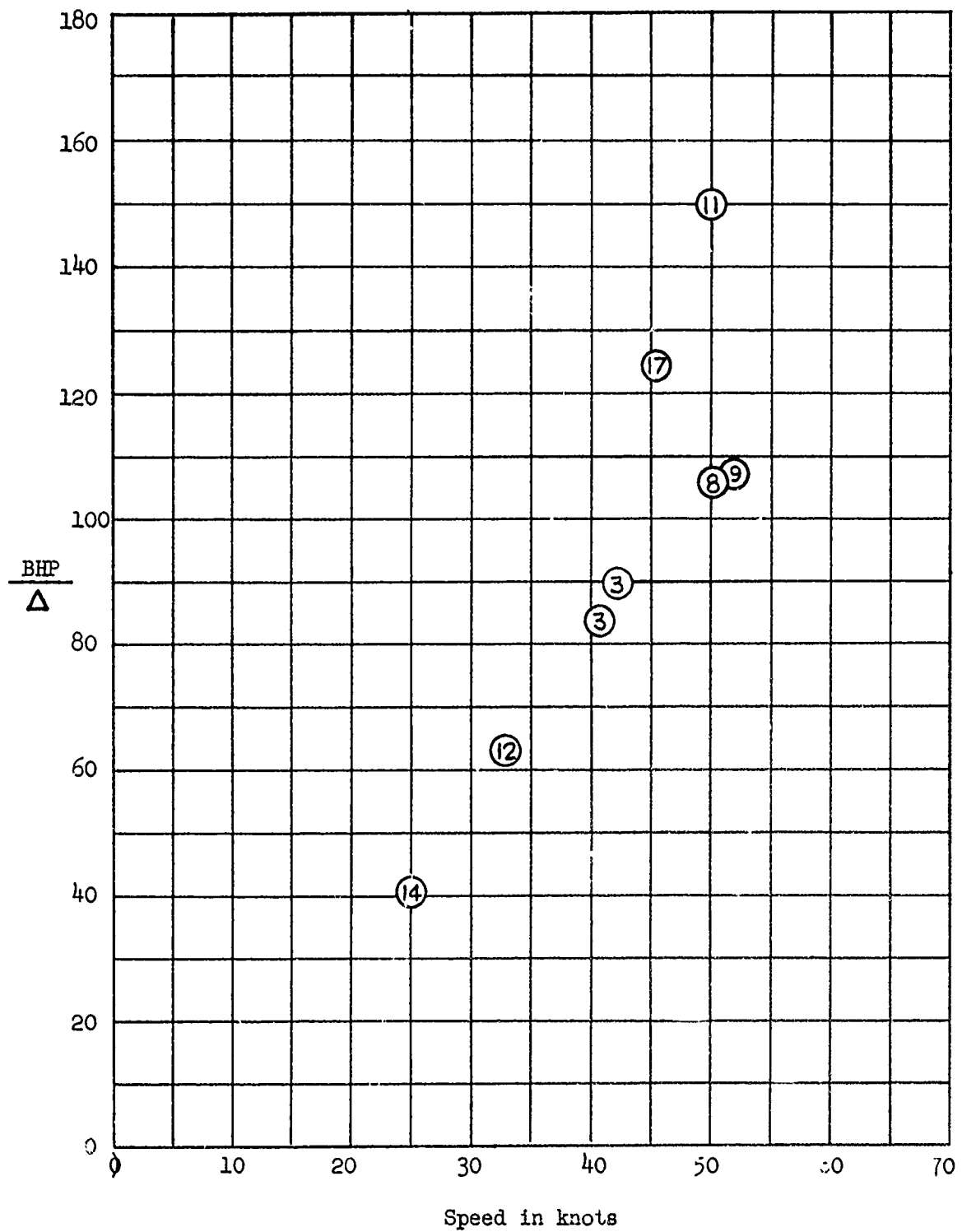


Figure 3: BHP/Δ vs speed in knots for several planing hulls

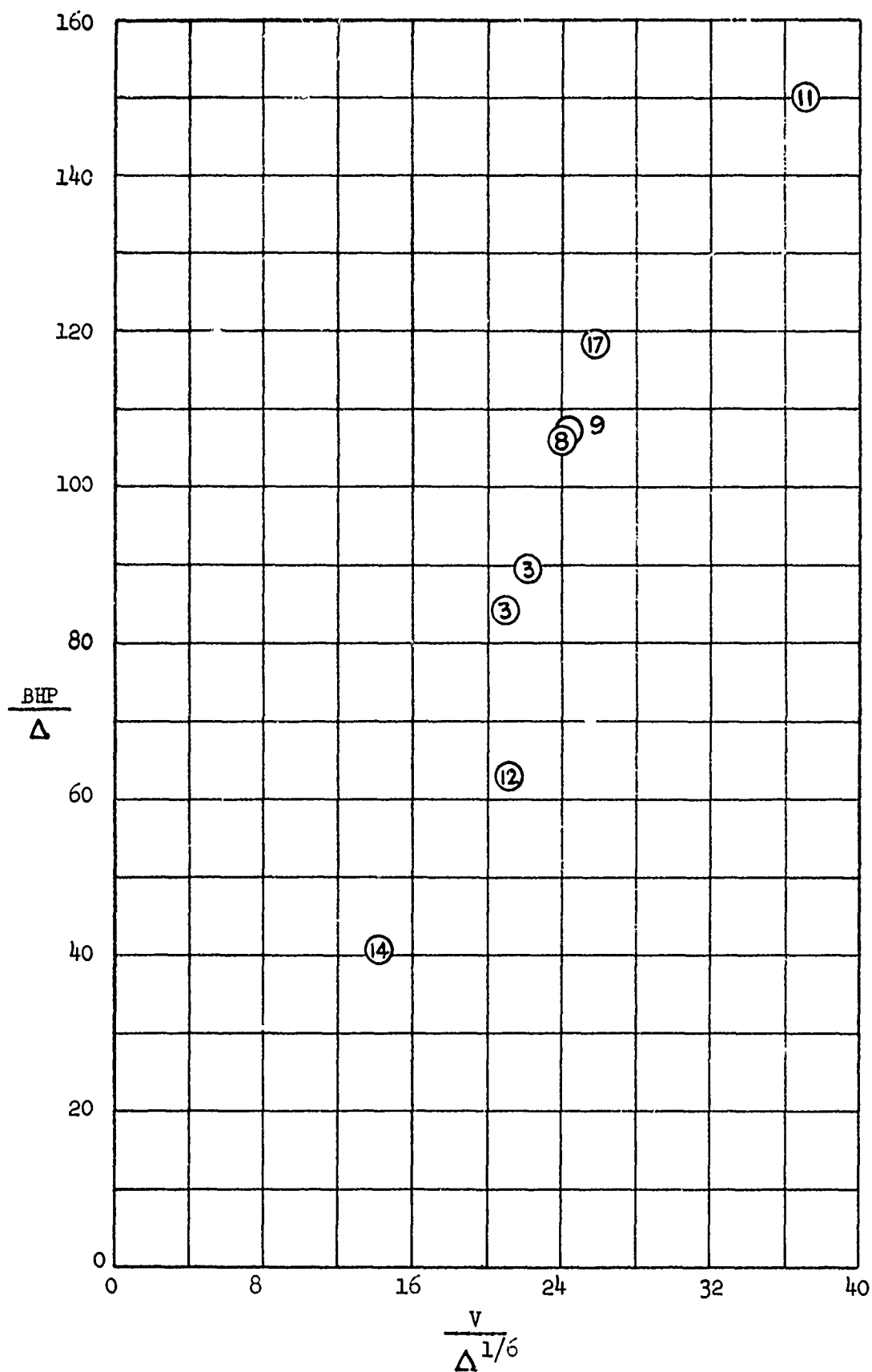


Figure 4:  $BHP/\Delta$  vs  $V/\Delta^{1/6}$  for several planing hulls.



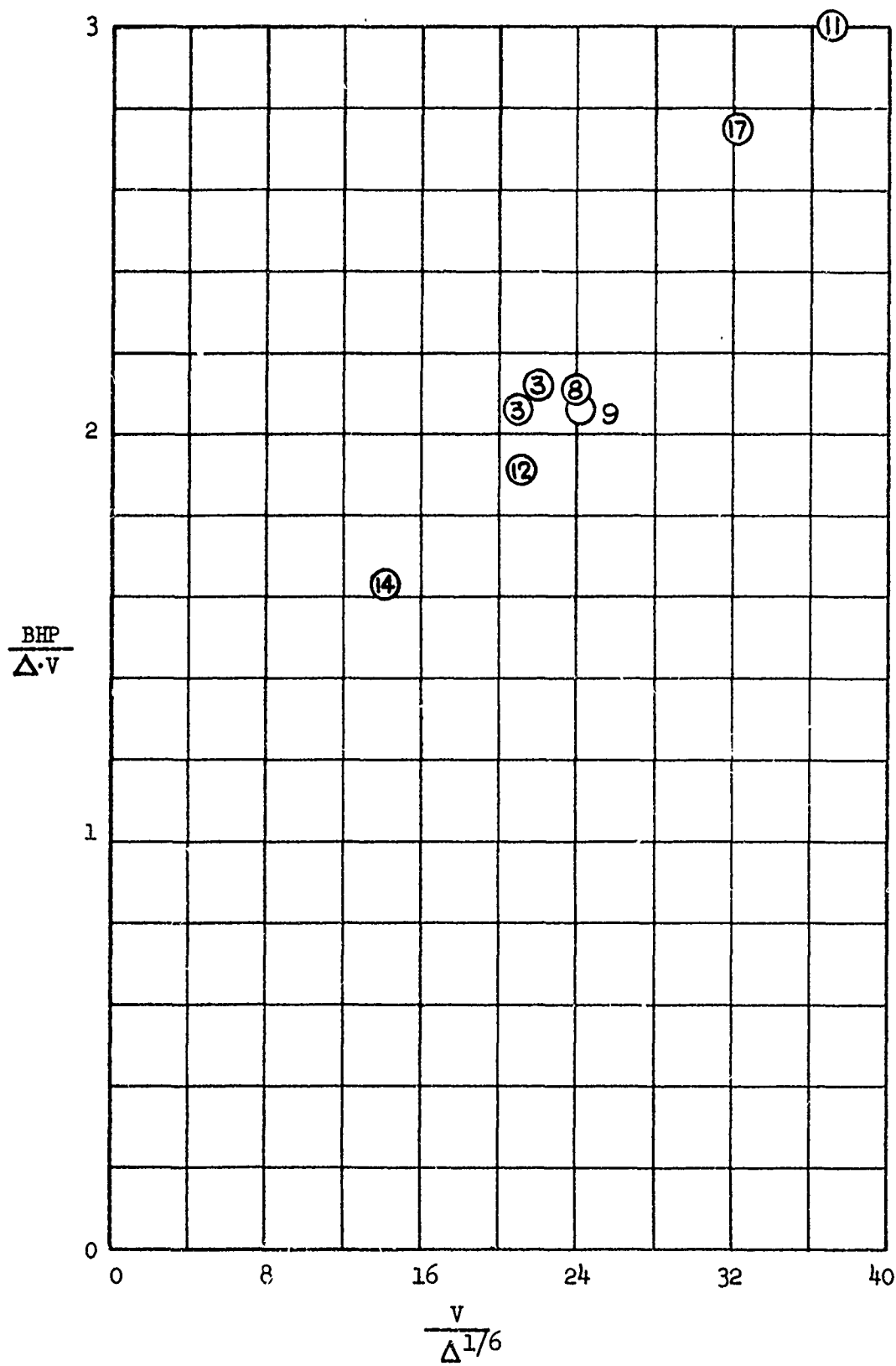


Figure 5:  $BHP/\Delta V$  vs  $V/\Delta^{1/6}$  for several planing hulls.

Some of the best work that has been done in this area is presented in Reference 16. This work provides not only a tool for making preliminary power estimates but also a "yardstick" for evaluating a design. It is one of the few dimensionally correct methods that have been published. It also contains accurate full scale trial data on a large number of boats of many types from small runabouts to PT boats.

Once again, it is strongly suggested that the designer collect as much accurate data as he can, both model and full scale, and plot them on a suitable grid. In the case of model data it is necessary to keep notes on the assumed propulsive coefficient if BHP is plotted, and in both cases the size of the boat should be noted. The references will provide much useful information. Reference 6 (three volumes) will be especially helpful for low speed results.

### C. DIRECT CALCULATION

Direct calculation means the determination of the performance of a design directly from its dimensions, taking into account all of the important factors which influence planing performance; principally, displacement, beam, l.c.g. and deadrise. The charts discussed in section IV.B. consider only displacement and sometimes length.

a. Clement

The design charts which Clement has developed from the equations of Shuford are very handy and permit easy visualization of the effect on performance of the various parameters. Their use is restricted to the full planing speeds. This method is presented in Reference 10, which also presents charts for the optimization of performance. The use of these charts is fully explained in the reference. The optimization charts are most useful when a stepped hull is to be designed and this approach is further developed in several references. Reference 11 presents a lifting surface approach to planing boat design. Reference 14 compares the 16 boats of the SNAME Small Craft Data Sheets (References 67 and 68 below) and 4 of the Series 62 models (Reference 25) with the Dynaplane; Reference 38 presents the results of extensive testing (variations in  $\Delta$ , l.c.g., step depth, etc.) of a stepped hull with a (adjustable) Plum-stabilizer (named after the inventor John Plum); and Reference 39 investigates the effects of varying the length-beam ratio and the l.c.g. of the Plum-stabilized Dynaplane.

b. Savitsky

For most planing boat designs there is a need to calculate performance at low speeds and in the hump region. The planing equations developed by Savitsky from the results of many model tests are valid down to speeds in the semi-planing range. They utilize the seaplane coefficients which is a very satisfactory way of handling planing phenomena.

It was seen, in Figure 2, that some powering data became more manageable when normalized on displacement in a dimensionally correct manner. Any dimension of the boat can be used for this purpose. In the case of the planing phenomena the beam has proven to be best. The reasons for, and use of, dimensionless coefficients have been explained by Stoltz in Reference 8 and in References 1, 2 and 3.

In Reference 9 Savitsky details the derivation of the equations which give the lift, wetted area, and center of pressure of flat and V-bottom surfaces, and presents curves which greatly simplify their use. In addition he outlines the procedure for using the material and gives sample calculations.

Savitsky Short Form. Contact with the small boat community reveals that there are a number of designers who feel that this approach is too complicated, and who fall back on the methods discussed in Section IV. B, above. It is hoped that after explaining the inadequacy of the simple powering equations it can be pointed out that the planing material is not only a powerful design tool but is also easy to apply. Even if the designer does not wish to understand the derivation of the equations he should study the design procedures well enough to see that most of the work has been taken out of them, particularly for the simple case which assumes all the forces to act through the center of gravity.

The forerunners of the equations were published in 1949 in:

65. "Wetted Area and Center of Pressure of Planing Surfaces", by B. V. Korvin-Kroukovsky, D. Savitsky, and W. F. Lehman, Davidson Laboratory Report 360, Sherman M. Fairchild Publication Paper 244, Institute of Aeronautical Sciences, New York, N.Y.

The present equations, which were developed in order to get better agreement, with the experimental data at low speeds, were presented in 1954 in:

66. "Wetted Area and Center of Pressure of Planing Surfaces at Very Low Speed Coefficients", Davidson Laboratory Report 493, Sherman M. Fairchild Publication Fund Paper FF-11, Institute of Aeronautical Sciences, New York, N.Y.

Not only were the new equations more accurate but they were simpler in form enabling a direct calculation to be made rather than a series of iterations. But the report itself was not handy to use in every day design work. The equations had been plotted in terms of quantities that were to be calculated, rather than in terms of quantities that could be measured on the drawings. They have been rewritten and plotted on a single chart, shown in References 8 and 9 where its use is fully explained. Use of this calculation method enables the designer to compute the change in resistance and trim due to variations in beam, l.c.g. position, deadrise, etc., and to make rational trade-offs.

Savitsky Long Form. This is the basic method of Reference 9, which does not make the simplifying assumptions of the "Short Form". As noted above, it accounts for the effects of trimming moments due to the thrust line and the frictional drag. If the calculations are to be made by hand the method is too laborious. But with the use of a computer program it is a cheap and easy calculation to make.

It is not necessary to know anything about computers or programming to make use of this service. There are a number of men who are in a position to do computer work for the designer. The designer can send in one page of input data and get back dozens or hundreds of pages of output data. The

computer service can handle all data preparation, key punching, etc. Figure 6 is a sample form that might be filled out. Actually no form is necessary. The information can be phoned in. Referring to Figure 6, water density, kinematic viscosity, and roughness allowance will almost always be constant for all conditions. Usually vertical center of gravity, shaft angle, depth of skeg, rudder clearance, and skeg drag lever arm are also constant. The thrust vector lever arm will vary only with l.c.g. The designer can specify as many values of any of the factors as he chooses. For example, if 3 weights, 3 beams, 3 l.c.g.'s, and 2 deadrise angles are to be investigated at 5 speeds, the total number of cases will be  $3 \times 3 \times 3 \times 2 \times 5 = 270$ .

One naval architect has revised the basic NAVSEC program to make the output easier to use. A sample output sheet is shown in Figure 7. It will be noted that the input for each case is shown on the output sheet; this is helpful for the convenient use of the output sheets. The output data are given in great detail: the trim angle, total drag and all components of drag, EHP, wetted area, wetted keel length, wetted chine length, draft at center of transom and the porpoising limit parameter. For those cases where the wetted chine length becomes negative the program has been corrected to handle it as a chines dry case.

#### D. MODEL TESTS

Prediction of performance from model tests is treated in References 1, 2, 3, 4, 5, 25 and 26. Particular attention is drawn to the statements on

FIGURE 6

COMPUTER PROGRAM

INPUT FORM

PRISMATIC PLANING HULL DESIGN CALCULATIONS

DATE

TITLE

WATER DENSITY ( $\text{lb-sec}^2/\text{ft}^4$ )

KINEMATIC VISCOSITY ( $\text{ft}^2/\text{sec}$ )

ROUGHNESS ALLOWANCE

HULL WEIGHT (lbs)

LONGITUDINAL C.G. (ft)

VERTICAL C.G. (ft)

AVERAGE BEAM (ft)

DEADRISE ANGLE (deg)

HULL VELOCITY (knots)

THRUST VECTOR LEVER ARM (ft)

SHAFT ANGLE (deg)

TRIM ANGLE (deg)

DEPTH OF SKEG (ft)

RUDDER CLEARANCE (ft)

SKEG DRAG LEVER ARM (ft)

HYDRODYNAMIC DESIGN OF PRISMATIC PLANING HULLS    APRIL 4, 1969  
COMPUTER PROGRAM ADAPTED FROM NAVSHIPS 0900-006-5310

ARTHUR'S BOAT WORKS INC. - DESIGN NO. 124 BY JOSEPH KOELBEL

CASE NUMBER    188

I N P U T   D A T A

DENSITY OF WATER            1.93840 LB.(SEC.\*\*2)/FT.\*\*4  
KINEMATIC VISCOSITY        0.122850E-04 FT.\*\*2/SEC.  
ROUGHNESS ALLOWANCE        0.00040

HULL WEIGHT                10000.0 POUNDS

LONGITUDINAL C. G.        12.000 FEET FROM TRANSOM  
VERTICAL C. G.            2.500 FEET FROM KEEL  
AVERAGE BEAM             10.000 FEET  
DEADRISE ANGLE            15.000 DEGREES  
HULL VELOCITY             30.000 KNOTS

THRUST VECTOR LEVER ARM    2.750 FEET  
SHAFT ANGLE                0.    DEGREES  
SKEG DEPTH                0.    FEET  
RUDDER CLEARANCE          0.    FEET FROM TRANSOM  
SKEG DRAG LEVER ARM        0.    FEET

O U T P U T   D A T A

SPEED COEFFICIENT                    2.824 (GREATER THAN 1)  
LIFT COEFFICIENT (DEADRISE SURFACE)    0.040  
HULL FRICT. DRAG LEVER ARM ABT C.G.    1.830 FEET

TRIM MOMENT ABOUT CENTER OF GRAVITY    0.202801E 03 FOOT POUNDS

TRIM ANGLE (TAU)                    2.859 DEGREES

TOTAL HULL DRAG                    1892.636 POUNDS  
    FRICTIONAL DRAG                1105.614 POUNDS  
    SPRAY DRAG                    287.553 POUNDS  
    SKEG DRAG                    0.    POUNDS  
    PRESSURE DRAG                499.470 POUNDS

EFFECTIVE HORSEPOWER                174.353 H. P.

WETTED AREA, SOLID                175.500 FEET\*\*2  
    WETTED KEEL LENGTH            25.490 FEET  
    WETTED CHINE LENGTH            8.414 FEET  
DRAFT, AFT AT CENTER OF TRANSOM    1.272 FEET  
MEAN WETTED LENGTH TO BEAM RATIO    1.695 (LESS THAN 4)  
PORPOISING LIMIT PARAMETER        0.142

PROGRAM PPH-1

ALFRED I. RAFF, NAVAL ARCHITECT

Figure 7    Typical prismatic planing hull computer program output.



pages 128 and 129 of Reference 4 regarding prediction of planing boat performance from tests of small models. Many of the references cited in the present work are model test reports from which the designer can select those of comparable characteristics (the appropriate size-weight parameter, length-beam ratio, section shape, etc.). Tests of sixteen of the models reported in these references have been grouped together and presented in a uniform manner in the:

\*67. "SNAME Small Craft Data Sheets",

which are available singly or in a set. Their use is explained in:

\*68 "How to Use the SNAME Small  
Craft Data Sheets for Design  
and for Performance Prediction",  
T and R Bulletin No. 1-23, SNAME

Reference 68 also gives the reasons for choosing the system of coefficients used.

When making a performance prediction from tests of a model geometrically similar to the full size boat there is no particular problem. But if the resistance of a new design is to be predicted from test results of a model of different design, some precautions must be observed. In general, they stem from the need to have the features which affect the performance prediction the same for both the full size boat and the model. A couple of examples will help illustrate the point.

If the resistance of a boat is to be predicted from Series 63, it must be noted that the total resistance coefficient,  $C_T$ , is based on the wetted area and the wetted area is that of the bare hull. The models had no appendages. Since turbulence was stimulated on the models, the Schoenherr friction coefficient,  $C_F$ , for fully turbulent flow corresponding to the

model Reynolds number can be subtracted from the total resistance coefficient to obtain the residual resistance coefficient,  $C_R$ , for the model.  $C_R$  is the same for the full size boat, but only if it is based on a comparable wetted area. The new design may have a skeg or S-frames or other features which influence the wetted area but which would not influence the wave-making. In fact, the basic assumption of this type of prediction is that the full size boat will have the same wave-making characteristics as the model. Therefore, in computing the residual resistance of the full size boat a fictitious wetted area equal to  $\lambda^2$  times the model wetted area must be used. Here  $\lambda$  is the ratio of ship size to model size, for example ( $LWL_{ship}/LWL_{model}$ ). The full size frictional resistance can be calculated from actual wetted area of the new design. Although there are other ways of handling the arithmetic, such as correcting the  $C_{Rship}$  for the difference in wetted area, the method outlined here is a satisfactory way to carry out the work and it provides a physical explanation which should illustrate the principle.

If a resistance prediction is to be made from Series 62 additional precautions have to be taken. The DTMB notation, used in the Series 62 report, as well as in all other planing model data published by that laboratory, is as follows:

- $A_p$  - projected planing bottom area, excluding area of external spray strips, ft.<sup>2</sup>
- $B_p$  - beam over chines, excluding external spray strips, ft.
- $L_p$  - length of planing bottom, ft.
- $\nabla$  - volume of displacement, ft.<sup>3</sup>
- LCG - longitudinal center of gravity location

The loading of the model is expressed as the area coefficient  $A_p/\nabla^{2/3}$ .

The LCG is given as the distance aft of the centroid of  $A_p$  expressed as a percentage of  $L_p$ .

If the new design is geometrically similar to the Series 62 model, there is no problem and the coefficients are satisfactory. But the hull form characteristics are based on the planform of the chine, that is, parts of the hull which are out of the water, particularly at high speed, and have no influence on the smooth water planing behavior. For example, in a given design the bow overhang and flare, forward of amidships, could arbitrarily be filled out from the narrow slab-sided shape of the early plywood runabouts to the full flaring form of some recent fiberglass models without changing the chine beam aft, the weight or the l.c.g. The actual smooth water planing performance of the boat would not be affected but, because the chine area would be increased and the centroid of the chine area moved forward, both the loading and l.c.g. coefficients would be changed in the DTMB notation. Consequently, two different predictions would be made for what is essentially the same boat. Therefore, to make an accurate prediction certain characteristics must be the same for model and ship, the ratio  $LCG/b$ ,  $C_{\Delta} = \Delta/wb^3$ , and  $C_v = V/(gb)^{1/2}$ . Perhaps the easiest way to accomplish this is to construct a fictitious Series 62 planform which has approximately the same length as the chine length of the

new design, with some adjustments as shown in Figure 8, and the same average beam in the afterbody (at about sta. 7 or 8), and then calculate its area and spot in the position of its centroid. (The drawing does not actually have to be made because of the known relationships between  $L_p$ ,  $B_p$ ,  $A_p$ , and the centroid, but its easier to visualize this way.) Now the actual position of the new design's l.c.g. can be located relative to the centroid of the fictitious area A and the area coefficient can be calculated based on the new design's displacement and the fictitious area  $A_p$ . Resistance values for the new design can now be determined as if it were geometrically similar to the series design, but still requires a three way interpolation for length-beam ratio, area (or loading) coefficient, and l.c.g. position. For the higher speeds Reference 25 gives a simple prediction chart using the seaplane coefficients which makes the calculation easy. But for the lower speeds the model data must be used.

It may be noted when making the interpolations for Series 62, that the models whose length-beam ratios and area coefficients bracket the new design will not have the same  $LCG/b$ ,  $C_\Delta$ , and  $C_V$ , as the new design. This is illustrated in Table II. The interpolations, however, will give a resistance curve for a model with the correct coefficients. The values of resistance of the other models, if cross plotted, will show the trends with variation in these parameters.

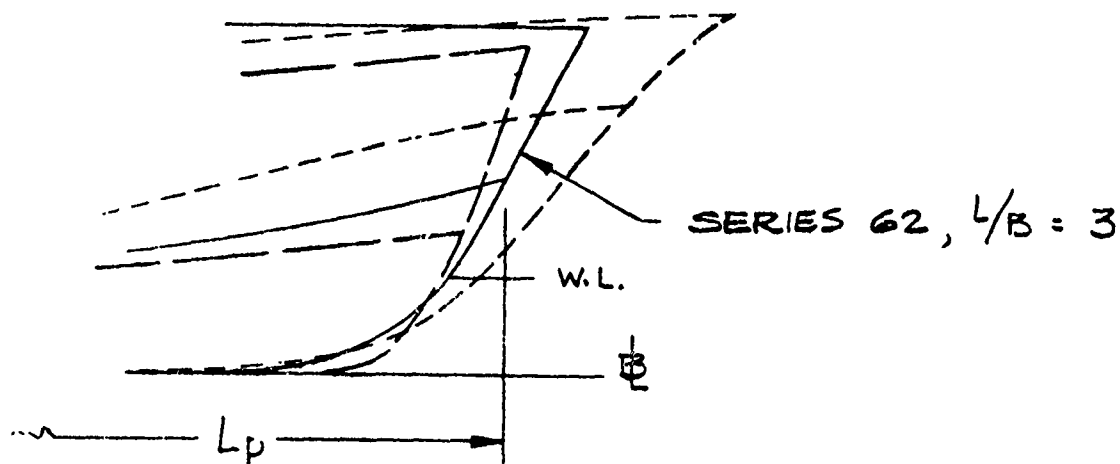


Illustration of how the bow of a design might vary without any significant effect on the smooth water planing characteristics. The forward end of  $L_p$  varies with chine height and bow overhang. A fictitious  $L_p$  must be chosen to define a Series 62 hull which will have an underwater form as much like the new design as possible, particularly in the afterbody, without regard to the dissimilarity in the chine planform. The average beam  $B_{PA}$  of the Series 62 hull should be taken equal to the average chine beam in the afterbody of the new design.  $A_p = L_p \times B_{PA}$ . For interpolation between length-beam ratios, use  $L_p/B_{PX}$  to be consistent with the models.

Figure 8: Various modifications of Series 62 bow.

TABLE II

DESIGN EXAMPLE FROM SERIES 62, REF. 25

CONSTANTS:  $\Delta = 15,000$  lb;  $\nabla = 234$  ft<sup>3</sup>;  $\nabla^{2/3} = 38$  ft<sup>2</sup>;  $\nabla^{1/3} = 6.15$  ft

$V = 65$  fps;  $V^2 = 4230$ ;  $F_v = V/\sqrt{g\nabla^{1/3}} = 4.71$

LCG = 8% aft of centroid of  $A_p$

		$A_p/\nabla^{2/3} = 7.0$	$A_p/\nabla^{2/3} = 6.5$	$A_p/\nabla^{2/3} = 5.5$
$L_p/B_{px} =$ 3.06	$A_p, B_{pa}$ $L_p, LCG$ $P/b, C_{Lb}$ $C_\Delta, C_v$	266 ft <sup>2</sup> , 9.3 ft 28.4 ft, 11.6 ft 1.25, .041 .292 3.74		209 8.25 25.2 10.3 1.25 .052 .417 3.96
$L_p/B_{px} =$ 3.5	$A_p, B_{pa}$ $L_p, LCG$ $P/b, C_{Lb}$ $C_\Delta, C_v$	266 8.75 30.7 12.5 1.43 .046 .350 3.86	247 8.4 29.4 12.0 1.43 .050 .395 3.94	209 7.7 27.0 11.0 1.43 .060 .512 4.11
$L_p/B_{px} =$ 4.09	$A_p, B_{pa}$ $L_p, LCG$ $P/b, C_{Lb}$ $C_\Delta, C_v$	266 8.05 32.9 13.4 1.67 .055 .450 4.02		209 7.14 29.2 11.9 1.67 .070 .645 4.26

NOTE:  $C_{Lb} = \Delta / 1/2 \rho v^2 b^2 = 2 C_\Delta / C_v^2$

LCG = p, ft. fwd. of transom

$B_{pa} = b$ , ft.

When making a performance prediction from tests of a single model, such as one of the SNAME Data Sheets, Reference 67 all the above recommendations must be observed. All the differences between the new design and the model must be considered and the necessary corrections and adjustments made. For any predictions from model tests it is necessary to be certain about how trim is defined and measured. For example, trim at any speed may be either the change from static trim or the angle of incidence of the mean buttock; in either of these cases the initial trim (at zero speed) of the mean buttock relative to the still water surface should be known to help relate the model to the full scale boat.

#### E. APPENDAGE RESISTANCE

The calculations referred to above pertain to the resistance of the hull only. Some specific models may have one or more appendages, and occasionally tests are for a fully appended model. It is necessary to calculate all the other components of resistance as well as that of the bare hull.

##### a. Keels and Skegs

Appendages of low aspect ratio, and which lie substantially in the flow lines of the boat in steady motion are considered to have only frictional resistance and their area is simply added to the hull wetted area.

##### b. Rudders and Struts

Appendages such as rudders and struts have both frictional resistance and form resistance. The following equation, adapted from Reference 69, below, for the usual range of  $t/c$  and type of section (not too blunt a leading edge and maximum  $t$  at 0.4 to 0.5 $c$ ) can be used for struts and rudders:

$$D_{AP} = C_D \frac{\rho}{2} A_{PF} v^2$$

- Where:  $D_{AP}$  - appendage drag
- $C_D$  - appendage drag coefficient based on planform area  
 $= 2 (C_F + .0008) [(1.2 t/c) + 1]$
- $C_F$  - Schoenherr friction coefficient based on total wetted area of appendages, and  $R_n$  based on chord of appendage
- .0008 - roughness allowance for short bodies
- $t/c$  - thickness to chord ratio of appendage
- $[(1.2 t/c) + 1]$  - separation drag factor
- $\rho$  - mass density of water, lb. sec<sup>2</sup>/ft<sup>4</sup>
- $A_{PF}$  - planform area, ft.<sup>2</sup>
- $v$  - speed, fps

Additional appendage drag information will be found in References

3, 4 and:

- \*69. "Fluid Dynamic Drag", by S. F. Hoerner, 148 Busteed Drive, Midland Park, N.J.

#### c. Shafts

For exposed circular shafts inclined to the flow the drag is calculated on the basis of the drag coefficient for a cylinder and the component of velocity normal to the shaft. The effect of rotation is ignored.

The formulas are:



$$D_s = C_D l dv^2 \sin^3 \theta$$

$$L_s = C_D l dv^2 \sin^2 \theta \cos \theta$$

Where:

$D_s$  = drag of shaft in direction of flow

$L_s$  = lift of shaft normal to flow

$C_D$  = drag coefficient of circular cylinder = 1.2

$l$  = exposed length of shaft, ft.

$d$  = diameter of shaft, ft.

$v$  = free stream velocity, ft./sec.

$\theta$  = angle of shaft inclination to flow

#### d. Boundary Layer

For those appendages close to the hull, such as scoops and strut palms, the effect of the boundary layer may be considered. The thickness of the boundary layer is given by the following formula (among others):

$$\text{For } 5 \times 10^4 < Re < 10^6$$

$$\frac{\delta}{x} = 0.37 Re^{-1/5}$$

$$\text{For } 10^6 < Re < 5 \times 10^8$$

$$\frac{\delta}{x} = 0.22 Re^{-1/6}$$

Where:  $\delta$  = thickness of turbulent boundary layer  
 $x$  = distance from leading edge  
 $Re$  = Reynolds Number  $vx/\nu$

References 2 and 3 give information on the thickness and velocity profiles of turbulent boundary layers. Reference 2 suggests that the average velocity can be taken as 0.75 times the free stream velocity.

There is an additional reduction in velocity under a planing boat due to the increased pressure under the hull. This is treated in Reference 9. However, the magnitude of this reduction is small and its extent from the surface is not well established. It is conservative to ignore this effect in planing boats. The phenomenon is the same as the change in local velocity around a displacement ship due to the pressure changes. This type of flow is known as potential flow and is treated in References 1 and 3.

### e. Inlet Openings

The whole subject of inlet and outlet openings is treated at length in Reference 69. This will apply to cooling water inlets for the engines, outlets for underwater exhausts, air intakes wherever they are a definite projection on an otherwise streamlined structure.

It should be noted that an inlet can be flush with the skin and still have drag because of the energy required to accelerate the air or water up to the speed of the boat, assuming the fluid makes a 90° turn as it enters the boat, i.e. the intake pipe is normal to the skin. This is a valid assumption for all internal systems except a water jet propulsion pump, where the flow is seldom turned 90°.

To provide a guide to the importance of calculating cooling water inlet resistance an approximate analysis was made which reveals that this resistance amounts to one percent of the total resistance at about 40 knots. The cooling water requirements and drag coefficient are based on data collected by Mr. John C. Angeli. The flow rate used is a low average for diesel engines. Manufacturers' recommendations vary from about  $3 \times 10^{-4}$  to about  $8 \times 10^{-4}$  ft<sup>3</sup>/sec/BHP. The actual rate for the specific engine should be used when available. Substituting the values 3 and 8 into the derivation yields speeds at which the inlet drag equals one percent of the total drag of 33 knots for high flow rates and 54 knots for low flow rates. The derivation, using the low average flow rate is as follows:

The cooling water flow rate,  $Q$ , ft<sup>3</sup>/sec is:

$$Q = 4.6 \times 10^{-4} \times \text{BHP} \quad (1)$$

Assuming a propulsive coefficient of 0.50:

$$\text{BHP} = 2 R_T v / 550 \quad (2)$$

For the typical inlet scoop with strainer the cooling water resistance,  $R_{CW}$ , lb, is:

$$R_{CW} = 0.6 \rho Q v \quad (3)$$

Substituting (1) and (2) into (3) and with  $\rho = (w/g) = 2$ :

$$R_{CW} = 2 \times 10^{-6} R_T v^2 \quad (4)$$

It is considered that although most resistance calculations are not accurate to anything like one percent, any known item of resistance should be calculated if it will be more than about one percent of the total. To solve for the speed at which  $R_{CW}$  becomes 1 percent of  $R_T$  let  $R_{CW} = 0.01 R_T$  and substitute into (4)

$$0.01 R_T = 2 \times 10^{-6} R_T v^2$$

$$v^2 = 5 \times 10^3$$

$$v = 70 \text{ fps} = 40 \text{ knots}$$

Therefore at boat speeds below 35 knots the cooling water scoops do not constitute a large increment of drag. The designer should use his own discretion depending on the accuracy of his data and of the remainder of his calculations.

#### F. AIR RESISTANCE

The calculation of air resistance is well covered in References 2, 3, and 69, and these should be consulted for detailed information. The air resistance is based on the above water frontal area and the speed of the boat through the air. The latter is the sum of the speed through the water and the wind speed. The frontal area should consider the hull in its running attitude at the speed in question, but no credit should be taken for blanketing of the superstructure by the bow. Although greater sophistication is presently possible in the choice of drag coefficients for various parts of the boat and various degrees of streamlining, a good formula to use is that of G. S. Baker quoted in Reference 3:

For superstructure:

$$R_{air} = .004 A_s V_k^2$$

For the hull there is a reduction in drag coefficient because of the sharp bow:

$$R_{air} = .0012 A_h V_k^2$$

These can be combined and written:

$$R_{air} = .0012 (3A_s + A_h) V_k^2, V_k \text{ in knots}$$

Except in extreme cases, air scoops should simply be considered in the frontal area and not calculated separately. An analysis similar to that for cooling water indicates that the resistance due to taking in the scavenging and combustion air of a typical diesel amounts to one percent of the total resistance at a speed of about 150 knots.

#### G. ROUGH WATER PERFORMANCE

A general discussion of rough water performance of power boats will be found in References 4, 5, 6, 20, 21 and 24. Some interesting results pertaining to a yacht hull and a trawler hull are given in:

70. "An Experimental Study of the Effect of Extreme Variations in Proportions and Form on Ship Model Behavior in Waves", by E. Numata and E. V. Lewis, 1957, Davidson Laboratory Report No. 643

Numerical data on some specific models will be found in References 28, 29 and other references in the complete Bibliography, listed under the subject headings "Seakeeping and Motions" and "Resistance". The first efforts at systematizing the available information on the calculation of motions, accelerations and added resistance of planing boats was reported in:

71. "On the Seakeeping of Planing Hulls", by Daniel Savitsky, 1966, Symposium on Small Craft Hydrodynamics, Southeast Section, SNAME

A first approximation of the vertical accelerations may be made by the methods given in:

72. "Engineering Approximation of Maximum Accelerations Experienced by Planing Craft in Rough Water", by J. K. Roper, Davidson Laboratory Report No. 1437

Systematic experiments with models having prismatic afterbodies and constant deadrise bows are being carried out at the Davidson Laboratory to investigate the effects of deadrise, trim, loading, length-beam ratio, speed, and wave proportions on the added resistance, on heave and pitch motions, and on impact accelerations at the bow and the center of gravity. The results for regular waves are reported in:

73. "A Systematic Study of the Rough Water Performance of Planing Boats", by G. Fridsman, Nov. 1969, Davidson Laboratory Report No. 1275

This report has been superseded by:

- \*74. A Systematic Study of the Rough Water Performance of Planing Boats, Phase II, Irregular Seas", by G. Fridsma, Feb. 1971, Davidson Laboratory Report No. 1495

This reference covers irregular sea tests of models having a more realistic bow shape, and permits a close approximation of the rough water performance of planing boats.

As good as the above works are, they still represent only the first steps in what is hoped to be a continuing program. For further background on seakeeping, see Chapter IX of Reference 1 and some of the references cited in Reference 71 above.

## V. PROPULSION

A good background in propulsion theory and practice will be found in References 1, 2, 3, 4, 5, 6 and:

- 75. "Marine Propeller Selection", by R. Kress and E. L. Lorenz, Jan. 1970, Paper No. 700094, Automotive Engineering Congress, Detroit, Michigan, SAE

Reference 75 provides a brief introduction to the whole subject of propeller selection, including cavitation problems and super-cavitating propellers. It also gives design charts for stock propeller types available off-the-shelf.

The most generally useful series of propeller charts are those of Troost and Gawn. The Troost series, also known as the Wageningen B-Screw series has been published over the years principally in Chapter VII of Reference 1, and in:

- 76. "Open Water Test Series with Modern Propeller Forms", by L. Troost, 1950-1951, NECI
- 77. "The Wageningen B-Screw Series", by W. P. A. Van Lammeren, et. al, 1969, Transactions SNAME

Reference 77 includes cavitation data on the Troost propellers.

The Gawn propeller data are presented principally in the following reports:



78. "Effect of Pitch and Blade Width on Propeller Performance", by R. W. L. Gawn, 1953, INA
79. "Effect of Cavitation on the Performance of a Series of 16-Inch Model Propellers", by R. W. L. Gawn and L. C. Burrill, 1957, INA

For "transcavitating" propellers see:

80. "Performance Data of Propellers for High Speed Craft", by R. N. Newton and H. P. Rader, 1961, INA

For supercavitating propellers the best paper to start with is: .

81. "Supercavitating Propeller Performance", by E. Venning, Jr., and W. L. Haberman, 1962 Transactions, SNAME

Most of the above reports consider only the open-water characteristics of the propeller. For information on hull-propeller interactions (propulsion coefficients) see References 27, 35, and :

82. "Correlation of Full-Scale Trials and Model Tests for a Small Planing Boat", by D.L. Blount, G.R. Stuntz, Jr., D.L. Gregory, and M.J. Frome, March 27, 1968, RINA.
83. "The Prediction of Power Performance on Planing Craft", by J.B. Hadler, Nov. 10, 1966, SNAME.

## VI. CONSTRUCTION

A basic library on the structural design and construction of power boats (covering both traditional and modern methods in most materials) should include the following: References 4, 5, 6, 32 (New Edition, brought up to date by Francis S. Kinney, 1962, Dodd, Mead and Co., New York), 63, and:

- 84. Boatbuilding, by H. I. Chapelle, W. W. Norton and Co., New York, N.Y.
- \*85. Boatbuilding Manual, by R. M. Steward, 1969, Poseidon Publishing Co., Lakeville, Conn. 06039
- 86. Problems in Small Boat Design, 1959, edited by G. T. White, Sheridan House, New York, N.Y. (Several Chapters)

- \*87. "Wood, a Manual for its Use as a Shipbuilding Material", Vol. I, II, III, and IV, NAVSHIPS 250-336 (1957-62), Supt. of Documents, Government Printing Office, Washington, D.C.
- \*88. A Guide to Sound Ship Structures, by A. M. D'Arcangelo, 1969, Cornell Maritime Press, Cambridge, Md.
- \*89. Formulas for Stress and Strain, by F. J. Roark, 1956, McGraw-Hill Book Co., Inc.
- \*90. "Adequate Strength for Small High Speed Craft", by P. J. Danahy, Jan. 1968, Marine Technology, SNAME
- \*91. "On the Structural Design of Planing Craft", by S. R. Heller, Jr., and N. H. Jasper, July 1960, Quarterly Transactions of RINA
- \*92. "Design and Construction of Metal Planing Boats", T. Graul and E. D. Fry, July 1967, Proceedings of Spring Meeting, SNAME
- \*93. "Aluminum Afloat", Aluminum Company of America, Pittsburgh, Pa.
- \*94. "Aluminum Boats", Kaiser Aluminum and Chemical Sales, Inc., Oakland, 12, Calif.
- 95. "Welding Aluminum", American Welding Society, 345 East 47th Street, New York, N.Y. 10017
- 96. "Hull Welding Manual", American Welding Society, 345 East 47th Street, New York, N.Y. 10017
- 97. "Recommended Aluminum Applications for Boats and Yachts", American Boat and Yacht Council, Inc., 420 Lexington Avenue, New York, N.Y. 10017
- 98. "Recommended Guide for Aluminum Crewboats and Yachts", by J. B. Rukin, Reynolds Metals Co., P. O. Box 2346, Richmond, Va. 23218

- \*99. "Marine Design Manual for Fiber-glass Reinforced Plastics", by Gibbs and Cox, 1960, McGraw Hill Book Co., New York, N.Y.
- 100. "Fiberglass Boats, Construction and Maintenance", by Boughton Cobb, Jr., Owens Corning Fiberglass Corp., 717 5th Avenue, New York, N.Y. 10022
- \*101. "Symposium on the Structural Design and Production of Small Boats and Yachts", 1966, N. Y. Metropolitan Section, SNAME
- 102. "Design and Construction of Fiberglass Boats from 60 to 120 Feet in Length, An International Survey", by K. B. Spaulding, Jr., and P. Silvia, Feb. 1967, Annual Meeting of Reinforced Plastics Division, Society of Plastics Industry, 250 Park Avenue, New York, N.Y. 10017
- 103. "Guide for the Selection of Fiberglass Reinforced Plastics for Marine Structures", 1965, T and R Bulletin No. 2-12, SNAME
- 104. "Ferro-Cement with Particular Reference to Marine Applications", March 1969, Pacific Northwest Section, SNAME
- 105. "Ferro-Cement for Marine Applications, An Engineering Evaluation, by J. F. Collins and J. S. Claman, March 1969, New England Section, SNAME

INDUSTRY ASSOCIATIONS FROM WHICH VALUABLE DESIGN INFORMATION MAY BE OBTAINED

The Aluminum Association  
 Marine Aluminum Committee  
 420 Lexington Avenue  
 New York, N.Y. 10017

The American Boat and Yacht Council, Inc.  
 Herman J. Molzahn, Secretary  
 420 Lexington Avenue  
 New York, N.Y. 10017

American Plywood Association  
1119 A Street  
Tacoma, Washington 98401

North American Ferro-Cement Association, Inc.  
1959 Old Middlefield Road  
Mountain View, California 94040

#### SOURCE ABBREVIATIONS AND ADDRESSES

ASNE      American Society of Naval Engineers  
         Suite 507, Continental Building  
         1012 14 Street N.W.  
         Washington, D.C. 20005

Reports    Clearinghouse for Federal Scientific and Technical Information  
suffixed   Sills Building  
AD 000 000 5285 Port Royal Road  
         Springfield, Virginia 22171

DTMB,  
NSRDC      Naval Ship Research and Development Center  
         (Including the David Taylor Model Basin)  
         Washington, D.C. 20034

ETT,  
DL          Davidson Laboratory  
         Stevens Institute of Technology  
         711 Hudson Avenue  
         Hoboken, New Jersey 07030

IAS          American Institute of Aeronautics and Astronautics  
         (Includes the former Institute of the Aeronautical Sciences)  
         1290 Avenue of the Americas  
         New York, N.Y. 10019

ISP          International Shipbuilding Progress  
         International Periodical Press  
         194 Heenraadssingel  
         Rotterdam, The Netherlands

NACA,  
NASA        National Aeronautics and Space Administration  
         400 Maryland Avenue S.W.  
         Washington, D.C. 20360

NECI        North-East Coast Institution of Engineers and Shipbuilders  
         Bolbec Hall  
         Newcastle-upon-Tyne, England

SAE          Society of Automotive Engineers  
         2 Pennsylvania Plaza  
         New York, N.Y. 10001

SNAME      The Society of Naval Architects and Marine Engineers  
74 Trinity Place  
New York, New York 10006

SSCD        Society of Small Craft Designers  
c/o Victor Harasty, Secretary  
22 2nd Avenue  
Port Jefferson, New York 11777

RINA,  
INA        Royal Institution of Naval Architects  
10 Upper Belgrave Street  
London, S.W. 1, England